Effects of aging on arterial distensibility in populations with high and low prevalence of hypertension: comparison between urban and rural communities in China

A. P. Avolio, Ph.D., Deng Fa-Quan, M.D., Li Wei-Qiang, M.D., Luo Yao-Fei, Huang Zhen-Dong, M.D., Xing Lian-Fen, and M. F. O’Rourke, M.D.

ABSTRACT Arterial pulse wave velocity, an established index of arterial distensibility, was measured together with arterial pressure in a group of 524 normal subjects of both sexes 2 months to 94 years old (mean age 45.6 ± 15.3 years [SD]) in rural Guangzhou, China, an area with known low prevalence of hypertension. Fasting serum lipid levels and overnight Na⁺ and K⁺ urinary excretion levels were determined in a subgroup of 104 subjects (ages 8 to 88 years). Comparisons were made with data obtained similarly from normal subjects in urban Beijing, an area with known high prevalence of hypertension. Serum cholesterol levels were similar and low in each group (Guangzhou, 4.34 ± 0.12 mmol/liter [SE]; Beijing, 4.49 ± 0.11 mmol/liter). Prevalence of hypertension (WHO criteria) was 4.9% (Guangzhou) and 15.6% (Beijing). In Guangzhou subjects pulse wave velocity was consistently lower in the aorta, arm, and leg, and increased to a lesser degree with age compared with Beijing subjects. Regression equations (x = pulse wave velocity [cm/sec], y = age [years]) were as follows: (1) aorta, Guangzhou: \( y = 5.1x + 533, r = .552, p < .05 \); Beijing: \( y = 9.2x + 615, r = .673, p < .001 \); (2) arm, Guangzhou: \( y = 0.61x + 817, r = .121, p < .05 \); Beijing: \( y = 4.8x + 998, r = .453, p < .001 \); (3) leg, Guangzhou: \( y = 4.43x + 718, r = .512, p < .05 \); Beijing: \( y = 5.6x + 791, r = .630, p < .001 \). Aortic pulse wave velocity in the Guangzhou group was consistently lower than that in the Beijing group when compared in subjects with the same arterial pressure at the same age, indicating a difference in aortic distensibility between the two groups, independent of arterial pressure. Results in two ethnically similar population groups with low serum cholesterol and low prevalence of atherosclerosis but markedly different prevalence of hypertension suggest that salt intake has an independent effect on arteriolar tone and arterial wall properties, with the former indirectly and the latter directly contributing to increased arterial stiffness with age.


WITH ADVANCING AGE the aorta and large arteries become progressively less distensible, and the ability to absorb pulsations from the ejection ventricle is reduced.1–3 Although it is well known that aging causes changes in the structural components of the arterial wall,3–5 there is no agreement on the effects of age-related disease such as atherosclerosis and hypertension on arterial stiffening. In Occidental populations, where the prevalence of atherosclerosis is greater than in Oriental populations,5,6 reduced arterial distensibility with age is often assumed to be caused by cumulative changes in medial matrix properties (an aging phenomenon) and increase in thickness of the intimal layer due to atheromatous processes. However, it has recently been shown1 that aging changes, even more marked than those seen in Occidental populations, are apparent in urban residents of Beijing, despite low prevalence of atherosclerosis in this community. Such findings suggest that atherosclerosis may not be a significant contributing factor to increased arterial stiffening with age.1 This leads to consideration of arterial pressure as a possible dominant determining factor.

A recent nation-wide survey in 29 provinces in China has shown that urban Beijing has the second highest prevalence of hypertension (after Tibet). The lowest was found in southern China, in the rural districts of...
Guangzhou. The difference in prevalence of hypertension in different regions has been attributed essentially to nutritional factors, specifically to dietary salt consumption.  

The purpose of this investigation was to seek further information on the effects of arterial pressure and age on arterial distensibility. This has been achieved by noninvasive measurement of arterial pulse wave velocity (an established index of arterial stiffness2-4) in the southern Chinese community in rural Guangzhou. This rural community has a known low salt intake and low prevalence of hypertension compared with the northern urban community previously studied.1 Both communities have equally low prevalence of atherosclerosis.

Methods

Procedures used in this study to measure arterial pressure, pulse wave velocity, and fasting serum lipid levels were identical to those previously described for the Beijing study.1 In this study additional measurements were made of urinary sodium and potassium excretion.

Subjects. The 524 volunteers for this study comprised approximately one-third of a single production brigade (She Gang) in Pan Yu county. All were rural workers who had participated in other previous surveys under the direction of the Public Health Bureau. An even age spread was obtained by random selection of normal subjects of both sexes from the brigade’s kindergartens, primary and secondary schools, adults engaged predominantly in rural activities, and persons living in retirement. All had been previously screened for symptoms or signs of cardiovascular or other disease. Subjects were not excluded on the basis of past disease or arterial pressure.

The age distribution for both male and female subjects is shown in table 1. Of the 524 subjects, one was an asthmatic, one had congenital heart disease (tetralogy of Fallot), one was anemic, and one had suffered a previous cerebral vascular accident with resultant left-side paralysis. Data from these subjects fell within the range of the group as a whole. Age of subjects ranged from 2 months to 94 years (mean 45.6 ± 15.3 years [SD]).

<table>
<thead>
<tr>
<th>Age range (yr)</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean age (yr)</td>
<td>n</td>
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<tr>
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<td>51–60</td>
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<td>61–70</td>
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<td>71–80</td>
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<tr>
<td>91–100</td>
<td>94.0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>240</td>
<td></td>
</tr>
</tbody>
</table>

Height ranged from 60 to 178 cm (mean 152 ± 18) and weight from 6 to 154 kg (mean 37.9 ± 20.7).

Procedure. The study was conducted in an evenly heated and ventilated room in the community hall at She Gang brigade, which was especially made available for this purpose during the month of October 1983. Temperature was fairly constant throughout the duration of the study (average room temperature 26°C). Subjects were recruited by volunteers from the Public Health Bureau and appointments were made to attend the clinic. The purpose and procedure of the study were explained and subjects were allowed to rest. All measurements were taken with the subjects recumbent. The protocol involved (1) measurement of blood pressure, (2) measurement of pulse wave velocity in the aorta, right arm, and right leg, and (3) second measurement of blood pressure. These data were obtained in all subjects. In a smaller subgroup of 104 subjects, measurements were obtained of fasting serum cholesterol and triglyceride levels and of urinary sodium and potassium excretion from 8 hr overnight urine collections. Blood and urine studies were performed in the same subject.

Arterial pressure measurement. A standard mercury sphygmomanometer was used to measure arterial pressure in the left brachial artery. A 13 cm cuff was used for adults and a pediatric 9.5 cm cuff was used for children younger than 10 years of age. The technique was similar to that used in a U.S. survey in 1977.11 The points of appearance (phase I) and disappearance (phase V) of Korotkov sounds were taken as systolic and diastolic pressure. Three consecutive readings of systolic and diastolic pressures were taken with an interval of at least 30 sec between inflations of the cuff. Blood pressure was then recorded as the mean of the three readings. Arterial pressure was measured at the beginning of the study and after flow recordings for measurement of pulse wave velocity. The average of the two measurements was taken as representative of the subject’s arterial pressure during the study. Mean arterial pressure (MAP) was estimated from systolic (SAP) and diastolic (DAP) pressures as MAP = DAP + 1/3(SAD – DAP).

Transcutaneous Doppler flow recordings. Two simultaneous Doppler flow recordings were taken among three separate locations: (1) at the top of the aortic arch at the base of the neck and right femoral artery in the groin, (2) at the right femoral artery and right dorsalis pedis or postibial artery in the foot, and (3) at the right brachial artery (middle of upper arm) and right radial artery at the wrist. The technique of flow measurement was identical to that previously described.1,12 Whereas in the Beijing study high-fidelity signals in the aortic arch could not be obtained in 29% of subjects and the pulse was detected in the common carotid artery, in this study all recordings could be faithfully obtained at the base of the neck. Transcutaneous flow waves were recorded on an FM tape recorder (TEAC, Model R61) and simultaneously at high speed (150 mm/sec) on a paper chart recorder (Siemens Mingograph) with high-frequency response (flat to above 60 Hz).

Flow measurements were obtained first in the arm, then between the aortic arch and femoral artery, and then in the leg. The whole procedure involving initial arterial pressure measurements, Doppler flow recordings, and final pressure measurement was usually completed within 30 min.

Determination of pulse wave velocity. Pulse wave velocity was obtained from the delay time between the simultaneously recorded flow pulses and the distance between the recording sites. The transit time was obtained from the foot-to-foot delay between the flow waves. The point at which the sharp systolic upstroke commenced was identified as the “foot” of the wave. When precise definition of this point was not possible, a tangent was drawn to the lower portion of the upstroke of the wave and to the late diastolic part of the preceding wave. The foot was
then taken at the intersection of the two lines. Transit times for 10 beats were averaged and designated Δt, the time required for the pulse to travel between the recording sites.

Distance (Δx) was measured between recording sites by means of a tape measure over the surface of the body. The site for aortic arch flow was taken as the midpoint of the manubrium sterni. For the three arterial segments (aorta, arm, leg), pulse wave velocity was determined as Δx (cm)/Δt (sec). As in the previous study,1 attention was focused on age-related changes in aortic pulse wave velocity as being the most physiologically important.

**Determination of serum lipid levels.** Fasting serum cholesterol and triglyceride levels were determined in a subgroup of 104 subjects (ages 8 to 88 years). The age distribution is shown in table 2. Blood was collected by venesection from subjects fasting overnight on the same day of the pulse wave velocity study. Total serum cholesterol and triglyceride levels were determined in the Pan Yu County Hospital laboratory by the standard colorimetric method with the ferric chloride–acetic acid–sulphuric acid technique, which was similar to that used in the previous Beijing study.1 Laboratories in both the Pan Yu County Hospital in Guangzhou and the Fu Wai Hospital in Beijing had similar standards for serum lipid determinations. Standardization was coordinated by experts from United States–China collaborative programs supported by NHLBI and WHO.

**Urinary excretion studies.** Overnight urine was collected in 103 of 104 subjects in whom fasting serum lipid levels were determined (table 2). Urine was collected for 3 consecutive nights and times of collection was noted for each subject. Aliquots were obtained for analysis of Na⁺ and K⁺ content. Analysis for Na⁺ and K⁺ was done with the flame photometry technique (Instrumentation Laboratory, Autocal Flame Photometer). Data for volume, Na⁺, and K⁺ were converted to an equivalent 24 hr urinary excretion period for the 3 consecutive days. Data for the 3 collection days were averaged. Conversion to 24 hr excretion was done with conversion factors obtained from a previous study13 (2.65 for Na⁺ and 3.75 for K⁺).

**Analysis.** All data for each subject were processed by a PDP 11/03 digital computer, and relationship between variables was obtained by means of least-squares linear regression analysis. Statistical differences were obtained by a two-sample Student t test.

### Results

Supine arterial pressure measurements showed relatively little change with age between the second and sixth decade (figure 1). Of the 524 subjects, 26 were classified as hypertensive according to the WHO criteria of systolic pressure over 160 mm Hg or diastolic pressure over 95 mm Hg. Of these 26, seven were men and 19 were women, all over the age of 44 years. For

<table>
<thead>
<tr>
<th>Age range (yr)</th>
<th>Mean age (yr)</th>
<th>n</th>
<th>Na⁺ (mmol/24 hr) 2 SE</th>
<th>K⁺ (mmol/24 hr) 2 SE</th>
<th>Na⁺/K⁺ 2 SE</th>
<th>Chol. (mmol/l) 2 SE</th>
<th>TG (mmol/l) 2 SE</th>
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</thead>
<tbody>
<tr>
<td>0–10</td>
<td>9</td>
<td>3</td>
<td>111</td>
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<td>2.2</td>
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<td>140</td>
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<td>14</td>
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<td>7.2</td>
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<td>145</td>
<td>27</td>
<td>23</td>
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<td>41–50</td>
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<td>83</td>
<td>17</td>
<td>15</td>
<td>6.1</td>
<td>1.7</td>
</tr>
<tr>
<td>61–70</td>
<td>68</td>
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</table>

Chol. = cholesterol; TG = triglyceride.

**FIGURE 1.** Comparison of supine systolic and diastolic pressures between normal Chinese subjects in rural Guangzhou (Pan Yu county) and urban Beijing.1 Values are mean ± 2 SEM. Rural Guangzhou subjects show little change in both systolic and diastolic pressure between the second and sixth decade, while urban Beijing subjects show a progressive increase in both, with a more marked increase in systolic pressure.
the group as a whole, systolic and diastolic pressure increased significantly after the first decade, after which there was little change until the sixth decade. This pattern contrasts markedly with that found in the urban Beijing group (figure 1), which showed progressive increase in systolic pressure after the second decade and in diastolic pressure after the first decade. The maximum difference in systemic/diastolic pressure between the two communities was found at the fifth decade: Beijing, 138/86; Guangzhou, 115/74 (p < .001).

The prevalence of hypertension found in urban Beijing and rural Guangzhou (Pan Yu County) in our investigations (figure 2) is in strong agreement with the much larger survey recently carried out in the whole of China. This indicates that both groups comprised a truly representative sample of the population in urban Beijing and rural Guangzhou.

Aortic pulse wave velocity increased with age. Figure 3 shows data from all subjects with a regression equation between age (x) and pulse wave velocity (y) of y = 5.1x + 553 (cm/sec) (r = .552, p < .05). This indicates an increase of 83% between birth and age 90. This is significantly lower than an increase of 135% found in the urban Beijing group. Figure 4 shows the data from both studies for different age groups. Aortic pulse wave velocity for the rural Guangzhou group was significantly lower than that in the urban Beijing group at all ages except the first and ninth decade.

Many studies have shown that while pulse wave velocity increases with age, it also increases with increasing arterial pressure. To attempt to normalize for blood pressure, results of aortic pulse wave velocity were tabulated for each decade in groups of 10 mm Hg in the range 51 to 150 mm Hg mean pressure (table 3). For each different pressure range aortic pulse wave velocity tended to increase with age. These data
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**TABLE 3**
Age distribution and aortic PWV at different mean blood pressures

<table>
<thead>
<tr>
<th>Mean pressure range (mm Hg)</th>
<th>Decade</th>
<th>Mean age (yr)</th>
<th>2 SEM</th>
<th>Mean PWV</th>
<th>2 SEM</th>
</tr>
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<tr>
<td>51–60</td>
<td>1</td>
<td>1.0</td>
<td>—</td>
<td>444</td>
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<td>61–70</td>
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<td>5.8</td>
<td>2.2</td>
<td>583</td>
<td>92</td>
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<td>71–80</td>
<td>22</td>
<td>6.0</td>
<td>1.1</td>
<td>590</td>
<td>65</td>
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<td>81–90</td>
<td>16</td>
<td>6.7</td>
<td>0.9</td>
<td>567</td>
<td>57</td>
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<td>91–100</td>
<td>5</td>
<td>7.2</td>
<td>1.2</td>
<td>546</td>
<td>129</td>
</tr>
<tr>
<td>101–110</td>
<td>4</td>
<td>18.3</td>
<td>1.7</td>
<td>787</td>
<td>101</td>
</tr>
<tr>
<td>111–120</td>
<td>1</td>
<td>20.0</td>
<td>—</td>
<td>1385</td>
<td>—</td>
</tr>
<tr>
<td>121–130</td>
<td>1</td>
<td>37.0</td>
<td>—</td>
<td>761</td>
<td>—</td>
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<td>141–150</td>
<td>1</td>
<td>94.0</td>
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<td>1039</td>
<td>—</td>
</tr>
</tbody>
</table>

PWV = pulse wave velocity.

were compared with data from the Beijing study in age-matched groups for different mean arterial pressure in the range 71 to 120 mm Hg, in groups of 10 mm Hg (figure 5). For all age groups after the first decade, aortic pulse wave velocity in the rural Guangzhou group was lower than that in the urban Beijing group. However, the marked increase in aortic pulse wave velocity with mean pressure at the same age found by Schimmler in German subjects was not seen in this investigation.

Pulse wave velocities in the arm and leg are shown in figure 6. The regression equations for age (x) and pulse wave velocity (y) for the arm and leg were:

- For the arm, \( y = 0.61x + 817 \) (cm/sec) \( (r = .121, p < .05) \) and \( y = 4.43x + 718 \) (cm/sec) \( (r = .512, p < .05) \), respectively. The increase in pulse wave velocity in the leg with age was similar to that seen in the aorta, but values at all ages were higher. A much smaller increase in pulse wave velocity with age was found in the arm. Compared with the urban Beijing group, the rural Guangzhou group showed a much smaller rate of change of pulse wave velocity in the arm with essentially a similar change of pulse wave velocity in the leg (Beijing: arm, \( y = 4.8x + 998 \); leg, \( y = 5.6x + 791 \)).

Serum cholesterol and triglyceride levels did not change significantly between age groups (table 2). The average for the whole group was 4.34 ± 0.12 mmol/liter (SE) cholesterol and 0.88 ± 0.06 mmol/liter (SE) triglyceride. Fasting serum cholesterol values were similar to those found in the Beijing study\(^1\) (figure 7) and to those reported for Korean subjects.\(^16\) As in our previous study in Beijing subjects\(^1\) and in Schimmler’s study in German subjects,\(^17\) no significant relationship was found between pulse wave velocity and serum cholesterol concentration.

Mean 24 hr urinary Na\(^+\) and K\(^+\) excretion levels for different age groups are shown in table 2. Na\(^+\) ranged from 83 to 148 mmol and K\(^+\) from 14 to 25 mmol. The overall average was 126 ± 6 mmol (SE) Na\(^+\) and 21.1 ± 1.5 mmol (SE) K\(^+\). Na\(^+\) excretion was significantly lower than the 230 ± 7 mmol (SE) previously found in factory workers in Beijing\(^10\) and was comparable to that found in farmers in rural Guangzhou district (132 ± 6 mmol [SE]\(^10\)) (figure 8). Na\(^+\)/K\(^+\) ratios were considerably lower in rural Guangzhou subjects (6.81 ± 0.19 [SE]) than in factory workers in Beijing\(^10\) (9.02 ± 2 [SE]).

**Discussion**

The social transformation and modernization program in China in recent years have resulted in an increase in living standards both in urban and rural com-
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FIGURE 5. Comparison of aortic pulse wave velocity between normal subjects in urban Beijing and rural Guangzhou (this study) at five levels of mean arterial pressure. Values are mean ± 2 SEM and arterial pressure range is indicated at the top of each graph (mm Hg). For all pressure levels after the first decade, pulse wave velocity in the rural Guangzhou community is consistently lower than that in the urban Beijing community.

FIGURE 6. Pulse wave velocity in the arm (top) and in the leg (bottom) of rural Guangzhou subjects. A much smaller change with age was found in the arm than in the leg. Both show a reduced rate of change compared with urban Beijing subjects.1

FIGURE 7. Fasting serum cholesterol levels in urban Beijing and rural Guangzhou subjects (this study). No difference was found between the two communities at all age groups. Values are mean ± 2 SEM.

Communities throughout the country. Longitudinal studies in migrating populations from Japan18 and other Pacific islands19 have shown that higher living standards and westernization of communities are associated with increase in prevalence of cardiovascular disease. Recent studies in China8,20 also report an increase in prevalence of cardiovascular disease in the last decade, related in part to improved detection techniques but mostly to changing living conditions and dietary patterns. In western countries the ubiquitous aspects of cardiovascular disease have generated massive efforts in highlighting the various risk factors associated with

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coronary artery disease, atherosclerosis, and hypertension. Similar trends are emerging in China with increased international cooperation and support from the WHO and NIH. Many collaborative programs have been established to standardize research techniques such as accurate determination of blood pressure, analysis of serum lipid levels, and compilation of nutritional data from standardized food tables. Because of the general consistency of daily living, work habits, and dietary patterns in both urban and rural communities in China, results obtained from recent comparative epidemiologic surveys involving large sample sizes (4 million) have provided accurate and specific information on the regional distribution of cardiovascular disease. These have generated many community control programs both in urban centers and rural districts.

As part of this international collaborative effort, our previous study in Beijing1 was aimed at obtaining information on the effects of age on arterial distensibility in an urban community in China.

Results showed a considerable increase in arterial pulse wave velocity with age, indicating a progressive decrease in arterial distensibility. Since prevalence of atherosclerosis in this community is known to be low, the increase in arterial stiffness with age was associated predominantly with medial degeneration. In comparison with other pulse wave velocity studies in western populations and in primate preparations of atherosclerosis, it was suggested that atherosclerosis does not contribute significantly to increase in arterial stiffness with age. This was also observed by Nakashima and Tanikawa, who showed that despite a large difference in severity of atherosclerosis between American and Japanese subjects, aortic distensibility measured postmortem in both groups was essentially similar. Thus the increase in arterial stiffness with age in the urban Beijing community was attributed to the relatively high prevalence of hypertension generally found in northern China.

This investigation carried out in a rural community in southern China supports this prediction. The communities studied in urban Beijing and rural Guangzhou had similar age distributions of total serum cholesterol levels (figure 7) but markedly different prevalence of hypertension (figure 2). Aortic pulse wave velocity and mean pressure tended to exhibit similar changes with age as did the prevalence of hypertension in both groups (figure 9). To our knowledge this is the first time that the pattern of change in arterial pulse wave velocity with age has been related to the prevalence of hypertension in a community as well as to difference in arterial pressure. Some studies have suggested that change in pulse wave velocity with age is entirely due to difference in arterial pressure. However, when the two groups were compared at similar pressure ranges (figure 5), aortic pulse wave velocity in the rural Guangzhou group was consistently lower than that in the urban Beijing group. This suggests that arterial stiffness at the same age and same mean arterial pressure is greater for an average normal subject in urban Beijing compared with one in rural Guangzhou.

The difference in prevalence of hypertension is strongly related to dietary salt consumption. Salt intake, as determined by urinary sodium excretion, averaged 13.3 g NaCl/day in urban Beijing and 7.3 g in rural Guangzhou. A smaller difference was found in sodium/potassium ratios (Guangzhou 7.74, Beijing 9.02). The lower pulse wave velocity found in the southern community at similar mean pressures suggests that similar factors responsible for reduced prevalence of hypertension may be responsible for reduced rate of arterial (presumably medial) degeneration. The question is whether salt intake has an independent effect on arterial distensibility. The results of these studies suggest that this might be the case. There is limited evidence in salt-loaded hypertensive rats that vascular lesions precede the development of hypertension and may be partly responsible for acceleration of increased arterial pressure. To obtain further information on this subject, a survey similar to that carried out in Beijing and Guangzhou is being planned for Tibet.
region with the highest prevalence of hypertension in China and with the highest consumption of salt.

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